Study on Enhancement of Hydroelectric Power Generation by Utilizing Plain Dam in the Shinano River

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ABSTRACT:
In Japan hydroelectric power is sustainable and a pure domestic energy with low carbon emission. It is necessary to promote a further enhancement in the future. While it has been difficult to construct a new dam due to the environmental impacts and fiscal tightening, plain dams have been recognized as leading plans for flood control in recent years, because basically there is no submerged houses in dams and they are environmentally friendly. In this study, we recognize plain dams are utilized not only for flood control but for water resources; enhancing effect of hydroelectric power is one of efficient and significant ways of their roles. This paper identifies the potential for the power development to examine increased power of the downstream power plant with assumptions of discharging water in accordance with the conditions. Experimental results from the Shinano River are being used as numerical model simulations to provide insights here.

Keywords: plain dam, hydroelectric power, water storage rate, water utilization calculation.

1. INTRODUCTION

In Japan, hydroelectric power is a sustainable and 100% domestic energy with low carbon emission and, it is necessary to promote further enhancement in the future. Constructing new dams has been facing difficulties because of financial tightening and environmental impact. On the contrary, plain dams have recently been recognized as leading plans for flood control as they do not basically involve submerging of land and are environmentally friendly.

We recognize that plain dams can be effectively utilized not only for flood control but for water resources, namely for enhancement of hydroelectric power generation. Thus the

target of this study is to examine the effect for power increase at the downstream power stations by properly discharging water from plain dams.
In this paper, plain dams on the Shinano River are chosen as the subject to seek potential of hydroelectric power development by modelizing water utilization calculation.

2. MODELIZATION OF ENHANCEMENT OF HYDROELECTRIC POWER GENERATION BY UTILIZING PLAIN DAMS

Plain dams have been recognized as an effective solution in many flood control plans in Japan. They are the flood control facility which is compatible with conventional land use by the establishment of servitude as they do not cause submergence; also they are nature friendly as they don't affect fish habitat since they do not segment rivers and do not change water levels. In addition, while MLIT (the Ministry of Land, Infrastructure, Transport and Tourism) has expressed their future flood control policy to rely on dams as less as possible (The Future Flood Control Measures, 2010), the fact is that heavy rains in recent years have often caused serious flood damages. Therefore, the demands for steady flood control are still important, and construction of new plain dams which store river water from the upper stream is expected in conjunction with river channel maintenance.

On the Shinano River and the Kiso River, there are power stations which cannot avoid considerable amount of ineffective discharge from run-of-river type power stations and power stations with a small dam. If plain dams which have water control effect for the datum points are constructed at the upper stream of these rivers, it is highly expected to increase steady power generation by storing river water in the plain dams not only when the river is flooding, but also when ineffective discharge is happening at the downstream power stations. The water is discharged when the available water amount is less than the maximum water intake amount at the downstream power stations.
In this study, we picked up the Shinano River which flows from Nagano Prefecture to Niigata Prefecture at the central area of Japan as a model to verify the potential and effect on enhancement of hydroelectric power generation by utilizing the plain dams as water resource. This river is suitable for the study subject since it requires reinforcement of river bank as well as construction of plain dams because of large scale flood disasters in the past, in addition that it has large scale power stations at the downstream.
Upon making the Shinano River Development Fundamental Policy (MLIT River Bureau, 2008) for the purpose of flood control, MLIT picks up Tategahana, Chikumagawa-Churyu, Saku, Azusagawa-Saikawa, Tsunan-miyanaka area in Nagano Prefecture and Niigata Prefecture as candidate sites for plain dams. Among these sites, we choose the plain dams at Tategahana area as the subject of this study since it is located just at the upper stream of the site where the Chikuma River bank was devastated in 1982 and 1983, and thus it is expected to have a great flood control effect. In addition, this plain dams can affect the increase of power generation at TEPCO (Tokyo Electric Power Company) Shinano River Power Station (Shinano River PS in Figure 1), and JR (Japan Railways) East Shinano River Power Stations (Senju PS, Ojiya PS, Ojiya Second PS in Figure 1). According to the MLIT's Policy, they are planning to have plain dams of 7 million m^2 surface area and 5 m depth to hold 35 million m^3 water. Figure 1 shows the location of the plain dams and the downstream power stations.

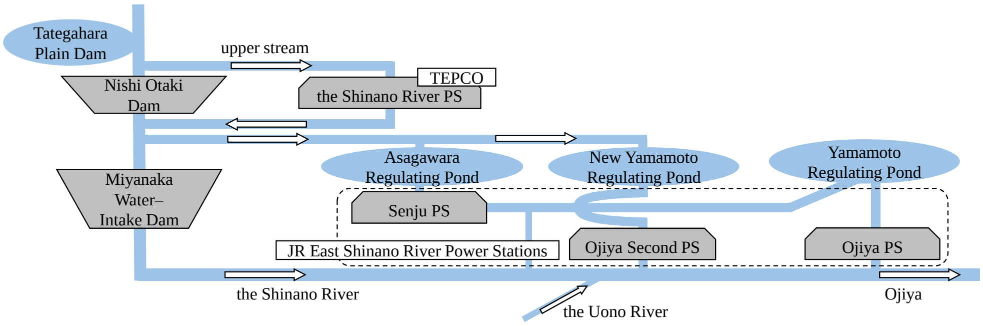

Figure 1. Map of the Shinano River Plain Dams and Downstream PS

3. CALCULATION OF ENHANCEMENT OF HYDROELECTRIC POWER GENERATION UTILIZING PLAIN DAMS AT THE SHINANO RIVER

3.1. The Calculation Subjective Years and the Setting of Plain Dams Operation Policy

The calculation subjective years are from 1999 to 2008. To make comparison among normal discharge, low water discharge and droughty water discharge, the years 2002, 2006 and 2008 were chosen as a rainy year, a normal year and a drought year respectively. Under the conditions set below, water utilization is calculated by setting water storage and water discharge to and from the plain dams based on the daily data.

3.1.1. Water storage condition

For storage of surplus water of the downstream power station to the plain dam, the normal flow at the Shinano River downstream datum point and the maintenance flow at the water intake point were set as the storage terms as being done at ordinary water utilization calculation.

・The water flow must be more than normal flow of 145 m^3/s（for non-irrigation period of from September 16th to April 27th, 115 m^3/s） at Ojiya downstream datum point.

・At TEPCO Shinano River Power Station and JR EAST Shinano River Power Stations, downstream outflow discharge must be more than the maintenance flow discharge at the intake points

・The intake point maintenance flow is set as follows:

Between 1999 to July 19th 2001 : TEPCO Nishi Otaki Dam 0.26 m^3/s
JR EAST Miyanaka Intake Dam 7 m^3/s
July 20th and after: In accordance with the test discharge plan (See Figure 2).

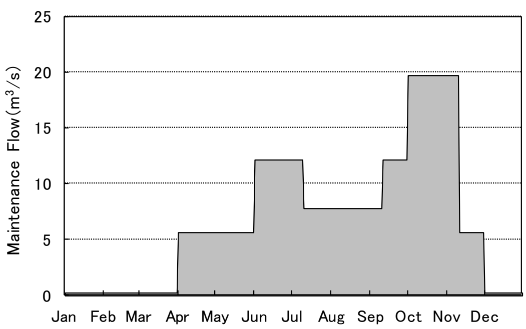

Figure 2. Maintenance Flow at Water-Intake-Spot of Nishi Otaki Dam

3.1.2. Discharge condition

When the river flow is low and the water intake is less than the maximum water intake amount at the downstream power station, the water from the plain dams is discharged to increase electricity. The specific water storage and discharge conditions of the plain dams (from 1999 to July 19th 2001) are shown in Figure 3.

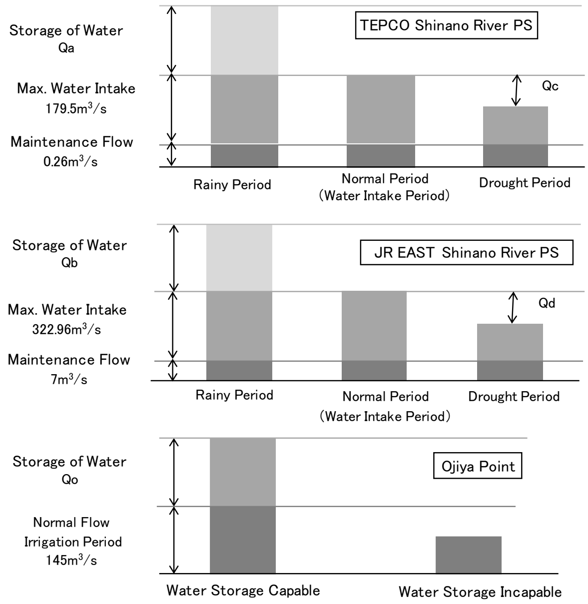

Figure 3. Conditions of Reservoir/Discharge from Plain Dams

As the maximum water intake amount and the maintenance flow between the two power stations are quite different from each other, the water shortage amount at the time of drought and the amount of surplus water are also quite different. Therefore, it is necessary to develop specific management policy to utilize the plain dams. Here, parameter k is given, which shows the water storage rate for the plain dams capacity Vp. When the water storage at each time period exceeds kVp, either Qc or Qd whichever is bigger, is discharged from the viewpoint of avoiding ineffective discharge at the time of flood. On the other hand, when the storage is less, storing the surplus of water up to the value Qc or Qd whichever is bigger, is selected from the viewpoint of effective use of water resource.

Table 1. Extra/Shortage Flow Volume at Power Station

	TEPCO Shinano River PS	JR EAST Shinano River PS
Flow More Than Max. Water Intake Amount.	Qa	Qb
Flow Less Than Max. Water Intake Amount.	Qc	Qd
Max. Water Intake Amount.	179.5 m^3/s	322.96 m^3/s

Qo : the flow volume exceeding normal flow at Ojiya .

1) $V(t) \geqq kVp$ (priority on water discharge)

The water amount to be stored to the plain dams: min(Qa, Qb, Qo)

The water amount to be discharged from the plain dams: max(Qc, Qd)

2) $V(t) < kVp$ (priority on water storage)

The water amount to be stored to the plain dams: min(max(Qa, Qb), Qo)
The water amount to be discharged from the plain dams: min(Qc, Qd)
The storage volume: V(t)

3.2. The Calculation of the Total Water Discharge from the Plain Dams

The water utilization calculation is conducted under the above conditions and the total annual water intake (Q) expected after the plain dams introduction is computed. Water utilization calculation was done by altering the parameter k, which determines the storage and discharge conditions of the plain dams, in increments of 0.1 in the range of 0.0~1.0. The calculation result of the typical case of the flow regime in 2006(a normal year), with Vp=35 million m^3, k=0.4 is shown in Figure 4. The upper figure of Figure 4 shows the daily inflow to the plain dams (plus) and the discharge amount from the plain dams (minus). The lower figure of Figure 4 shows the storage rate of the plain dams, and 100% means full water.

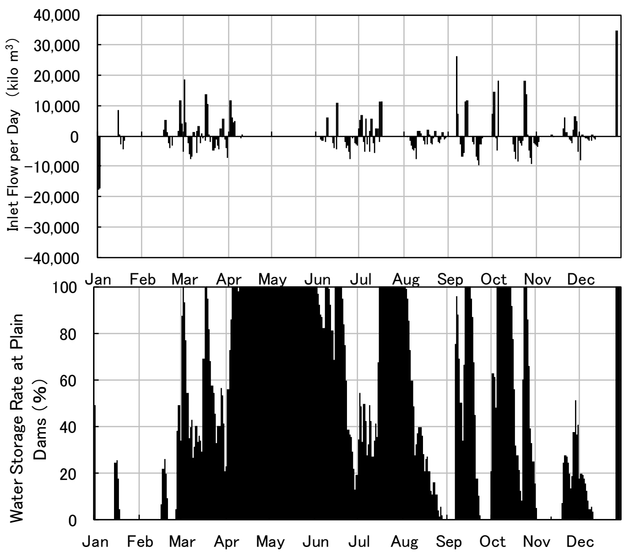

Figure 4. Water Utilization Calculation Based on 2006 Flow

In winter, the water storage rate often marks 0% because the river flow declines. The plain dams become full at around April because of snowmelt, and this condition lasts until around June. In July, water storage decreases because the supplement water is supplied from the plain dams to the power station to make up the decrease of river flow. The total annual discharge amount is about 400 million m^3, and this is about 11.4 times as much as the storage capacity of the plain dams. As the other dams in Japan usually supply less than double or triple amount of their own capacity, it is obvious that the efficiency of this plain dams is extremely high. This is because the plain dams are located in the middle reach of the river system and it makes it easy to collect ineffective discharge, and also because the flow regime of the Shinano River is quite good.

As Figure 5 shows, the total discharge amount changes in accordance with the change of the value of k. When the value of k=0.0 and 1.0, the discharge amount becomes less compared to other values. Though the size of the plain dams affects, the total discharge reaches the maximum at the value of k=0.2~0.4. It was found that the total discharge amount becomes the largest regardless of the size of plain dams when the value k=0.4. Therefore, this value is used as the prototype for the following study.

On the presumption that water storage is 35 million m^3, water utilization was calculated for nine years. The calculation for 2004 was unable because of missing data. The result is shown in Figure 6.

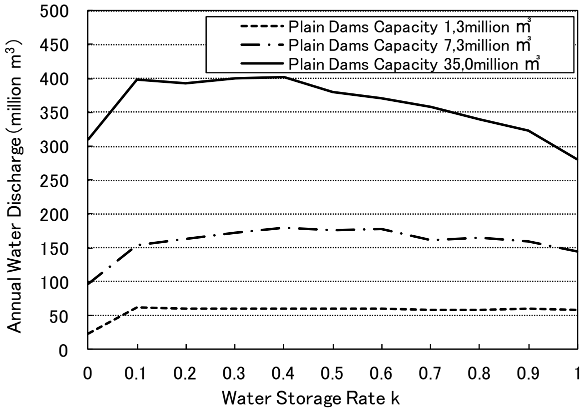

Figure 5. Water Storage Rate and Annual Water Discharge

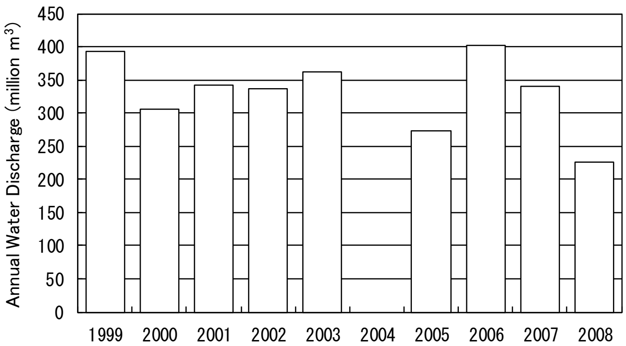

Figure 6. Annual Water Discharge by the Year

Though the Shinano River Basic Policy for River Improvement (MLIT River Bureau, 2008) mentions developing the plain dams in Tategahana area, it appears to be difficult to improve all of the 35 million m^3 at once. Therefore, step-by-step development will probably be implemented. In this study, water utilization calculation was done for 20 different plain dams capacities from 1.3~35 million m^3. The result is shown in Figure 7. There is an inflection point of the total discharge from the plain dams at around capacity 10 million m^3. Total water discharge effectively increases in proportion to the plain dams capacity until it reaches 10 million m^3 though the increase level go down from this point.

In addition, according to the Shinano River Basic Policy for River Improvement (MLIT River Bureau, 2008), four candidate plain dams sites other than Tategahana area are picked as mentioned in Chapter 2, which are all located at upper stream of both power stations. The total storage volume of them reaches 48million m^3. Therefore, three patterns of calculation were done using the combination of these four areas to see the effect, supposing that these plain dams are put in use in addition to Tategahana. The subject years are 2002, 2006 and 2008, which are a rainy year, a normal year, and a drought year, respectively. The result is shown in Figure 8. The better the flow is and the bigger the plain dams are, the more the total discharge volume is realized.

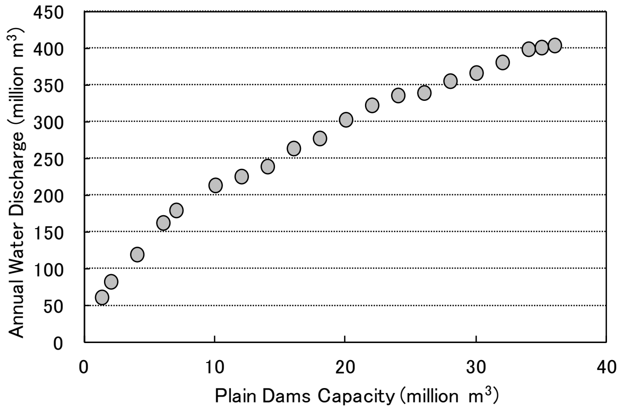

Figure 7. Plain Dams Capacity and Annual Water Discharge

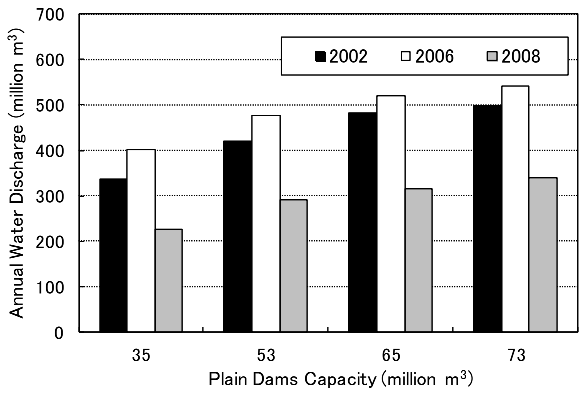

Figure 8. Plain Dams Capacity and Annual Water Discharge

3.3. The Calculation of Power Increase and Environment Conservation Effect by Plain Dams Development

According to the water utilization calculation shown in the previous section, we have calculated the electricity increase effect produced by the development of the plain dams by using Eq. 1. To make it more specific, the total annual water intake after installation of plain dams (Q_2) is compared with the current water intake amount (Q_1) and; the expected electricity increase amount ΔP is estimated by making proration based on total annual water intake ratio against the actual annual power generation P_1.

$$\Delta P = P_1 \times (Q_2 - Q_1) / Q_1 \times (h + \Delta h) / h \qquad (1)$$

h : the water intake level before installation of the plain dams.

Δh : the difference of water intake level after the installation of the plain dams.

Actually, the expected electricity increase differs due to the water level changes at Nishiotaki Dam and Miyanaka Water Intake Dam. But the water level change is little enough to ignore because the height of both dams are low and the volume for the electric generation is small. Thus, $\Delta h=0$. The electricity increase in normal year flow regime (2006) with k=0.4 and water storage up to 35 million m^3 is shown in Figure 9. Up to 192 kilo MWh of annual generation increase is expected in total from both power stations. This figure corresponds to about 6.2% of the current electric generation, and considering the fact that an average electric consumption of a standard household is about 283.6 kwh (Federation of Electric Power Companies Website), it is estimated that this makes it possible to supply electricity for about 56,000 households annually.

Hydroelectric power stations emit little CO_2 to generate electricity, so that an effect on environment conservation by this method is estimated. In Japan, the newly built power stations are mainly LNG type thermal power stations in recent years. On assumption that plain dams utilization is able to replace the LNG type power stations, CO_2 reduction volume is calculated by multiplying the difference of carbon emission per 1Mwh between hydroelectric power generation and LNG type power generation (11g/kwh, 608g/kwh respectively (Central Research Institute of Electric Power Industry, 2010)) with the total annual power generation. The result is shown in Figure 10. Though it depends on the size of the plain dams, it is estimated that CO_2 is reduced by about 17,000~115,000 tons.
One of the popular measures for CO_2 reduction is forestation. 1ha of cedar forest attains about 2.1 tons of CO_2 fixations per year (Forestry Agency Website). If the above CO_2 reduction is divided by this value, the plain dams utilization corresponds to about 8,100~55,000 ha of cedar forestation in terms of environment conservation.

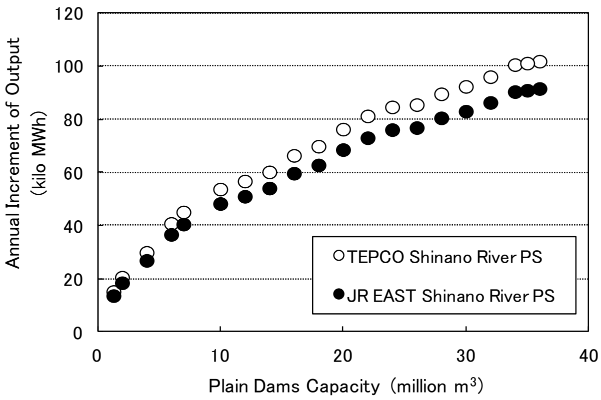

Figure 9. Plain Dams Capacity and Annual Increment of Output

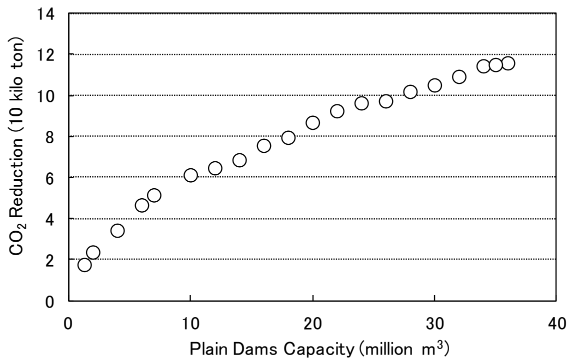

Figure 10. Plain Dams Capacity and CO_2 Reduction

3.4. Examination on Project Cost.

To examine the project cost, a regression equation is formulated using the capacity of the plain dams constructed in Japan (set as ”*x*”) and the operation cost (set as “*y*“).
(see Figure 11)

$$y = - 8\times10^{-6}x^2 + 2971.3x \quad (2)$$

According to Eq. 2, the project cost for Tategahana plain dams amounts 941,955 thousand dollars. Plain dam is for multipurpose use and the figure includes the cost for flood control. Based on the fact of general multipurpose dams like Aseishikawa Dam and Unazuki Dam, 3% is the rate of share which electric power companies usually pay (The Japan Dam Foundation, 2013). Therefore, 3% of the total operation cost 941,955 thousand dollars makes 28,260 thousand dollars . The unit cost of electricity is 0.15 thousand dollars per 1Mwh, assuming that 192 kilo MWh of electricity increase is expected from the 35 million m^3 plain dams. Compare this result with the unit prices(per 1MWh) of the typical multipurpose dams on Table 2, and you can see that the plain dams are also competitive from the viewpoint of operating cost.

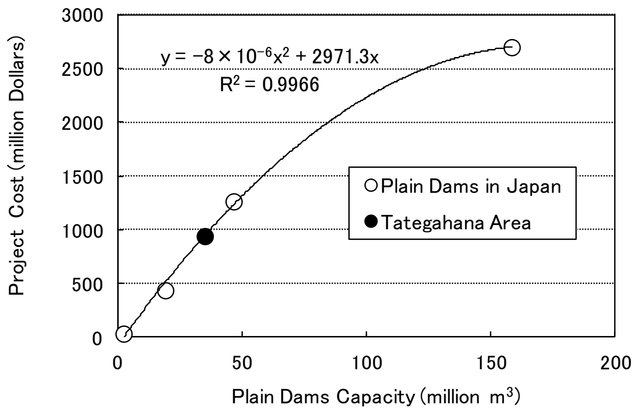

Figure 11. Plain Dams Capacity and Project Cost

Table 2. Unit Price per 1MWh for Dam Control Power Generation at Typical Multi-Purpose Dams

Dam	Project Cost (million Dollars)	Output (MWh)	Unit Price per 1MWh ($1thousand/MWh)
Sagae	4.96	4,542	1.09
Shichikashuku	19.47	23,319	0.83
Sagurigawa	12.65	8,606	1.47
Tainai	12.26	10,705	1.15
Hitokura	8.13	5,055	1.61

4. CONCLUSIONS

This research selected the Shinano River as study subject to examine the hydroelectric power enhancement by utilizing plain dams which MLIT is planning to develop. Furthermore, we examined effect of electricity increase under various flow regime and operating situations, and plain dams scale.

The conclusions of the study on the Shinano River Tategahana area are as follows:

・By setting an optimum storage rate " k", effective electric generation is expected and; when k=0.2~0.4, total water discharge reaches the maximum. Also, the best value of k varies depending on the size of plain dams.
・The larger plain dams are, the more supplementary water supply is realized. The supplementary water amount corresponds to 11.4 times of the plain dams storage capacity (under the conditions of a normal year, and plain dams scale is 35 million m^3), and it proved to be effective as much as to normal dams. Up to the size of 10 million m^3, the performance of plain dams is the highest.
・If 35 million m^3 plain dams are constructed, about 192 kilo Mwh of electricity increase is expected from both power stations in total. This is equivalent to the annual electric consumption of about 56,000 households.
・The electricity increase by using this method is evaluated that it can reduce about 17 kilo~115 kilo tons of carbon emission a year, and this is equivalent to 8100~55000 ha of cedar plantation.
・The unit cost (per 1Mwh) of hydroelectric power generation by using the plain dams is about the same as that of conventional dams.

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